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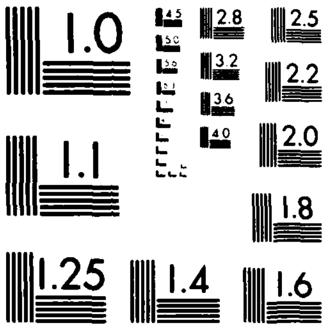

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AFRRI TECHNICAL REPORT

Use of a radiotherapy treatment-planning computer for dosimetry of the AFRRI Cobalt-60 Facility

TR84-5

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Research was conducted according to the principles enunciated in the "Guide for the Care and Use of Laboratory Animals" prepared by the Institute of Laboratory Animal Resources, National Research Council.

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Patterns of whole-body depth dose and tissue-to-air ratios (TAR's) were calculated for cylindrical phantoms using a computer for treatment planning, and then compared to those measured in the Cobalt-60 Facility at the Armed Forces Radiobiology Research Institute. The measured TAR's agreed well with the computer-calculated TAR's for one computational mode but not for another. The calculated and experimental depth-dose patterns agreed well at the central cross sections of the phantoms, but differed significantly at the cross sections near the end of the phantoms. These data demonstrate the degree of nonuniformity of dose in cylindrical phantoms irradiated in the Cobalt-60 Facility. They also point out the usefulness of a treatment-planning computer in characterizing distributions of depth dose.

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CONTENTS

INTRODUCTION

This study examined the feasibility of using a radiation therapy treatment-planning computer (TPC) designed for clinical radiotherapy, to calculate patterns of depth dose and tissue-to-air ratios (TAR's) for objects irradiated in the Cobalt-60 Facility at the Armed Forces Radiobiology Research Institute (AFRRI). The TPC was used to calculate patterns of depth dose for four cylindrical phantoms of different sizes. These results were then compared to patterns of depth dose and TAR's measured in the cylindrical phantoms exposed both unilaterally and bilaterally in the Cobalt-60 Facility. The effects of various parameters [such as distance from source, size of phantom, and type of exposure (unilateral or bilateral)] on the patterns of depth dose and TAR's were also investigated.

MATERIALS AND METHODS

Treatment-Planning Computer

The computer analysis was made with a TPC [Atomic Energy of Canada, Ltd. (AECL) Program Number QTP 11, *Version Number* TPO5A] at the Naval Hospital, Bethesda, Maryland. Two modes of computation were used: fixed rectangular beam mode and irregular field mode.

The fixed rectangular beam mode used a 35 cm x 35 cm collimated beam as the source, and corrected for the contoured surfaces of the phantoms. Because of this correction feature, patterns of depth dose were determined with this mode. The irregular field mode considered the source to be uncollimated but did not account for the effects of a contoured surface. This mode is used primarily for point dose calculations; in this study, it was used to calculate midline TAR values.

Cobalt-60 Facility

Experimental work was done in the AFRRI Cobalt-60 Facility (described in reference 1). The facility has two planar sources, which may be raised either separately for unilateral irradiations or together for bilateral irradiations. As of April 1983, each source contained the maximum of 48 cobalt ribbons with an activity of 833 Ci each.

Phantom Specifications

The dimensions of the cylindrical Plexiglas phantoms used in this study are shown in Table 1. The phantoms were filled with tap water and equilibrated overnight at room temperature for all measurements. Because of the construction of the short phantom, measurements of depth dose could be experimentally performed only on its central axis.

Table 1. Dimensions of Phantoms Used for Depth-Dose Measurements

	Phantom			
	Large	Medium	Small	Short
Height (cm)	32.0	32.0	32.0	15.7
Diameter (cm)	15.0	12.6	9.5	7.5
Wall Thickness (mm)	4.5	6.0	3.0	3.0
Closest Distance* (mm)	8.0	13.5	11.0	—

*Refers to how closely ionization chambers were placed to edge of phantom, due to radius of chamber holder and thickness of phantom wall, for front, back, and side measurements

Measurements

Patterns of depth dose and TAR's were measured using five different 0.5-cc tissue-equivalent (TE) ionization chambers. Two of these chambers were manufactured by Exradin; the other three were fabricated at Illinois Benedictine College (Lisle, Illinois) (2). No significant differences were observed among the chambers when comparisons were made among them by repeating certain measurements. A bias of ± 100 volts was applied across the chambers for all measurements, and an average of the readings at opposite polarities was taken to minimize the effects of the cable currents, which were typically 1%-2% of the ionization currents.

The ionization current was read by a Keithley 616 digital electrometer (Keithley Measurements Inc., Cleveland, Ohio). Readings were taken at 5-second intervals through a Hewlett-Packard Data Acquisition unit (Model 3421A) (Hewlett-Packard Company, Corvallis, Oregon) connected to a Hewlett-Packard desk-top computer (Model 85).

Calculations

The TPC was used to calculate midline TAR values and to print contour plots of the patterns of depth dose normalized to the dose received at the midline of the phantom.

To determine experimental TAR values, the ionization current obtained when the chamber was placed at the center of the phantom was divided by the current measured with the chamber free in air (using a 0.5-cm buildup cap). Experimental values of depth dose were determined by measuring the ionization current at different points inside the phantoms, and then normalizing each reading to the midline reading for the central section.

RESULTS

Representative depth-dose printouts for the phantoms are shown in Figures 1 and 2. Table 2 lists calculated and measured midline TAR values, which agreed within ± 2.5% in all cases. The calculated TAR's in Table 2 were taken from the irregular field mode of the TPC. The fixed rectangular beam mode produced TAR's that differed significantly from those of the irregular field mode. This was apparently due to the use of standardized TAR tables with the fixed rectangular beam mode, as opposed to actual TAR calculations used in the irregular field mode.

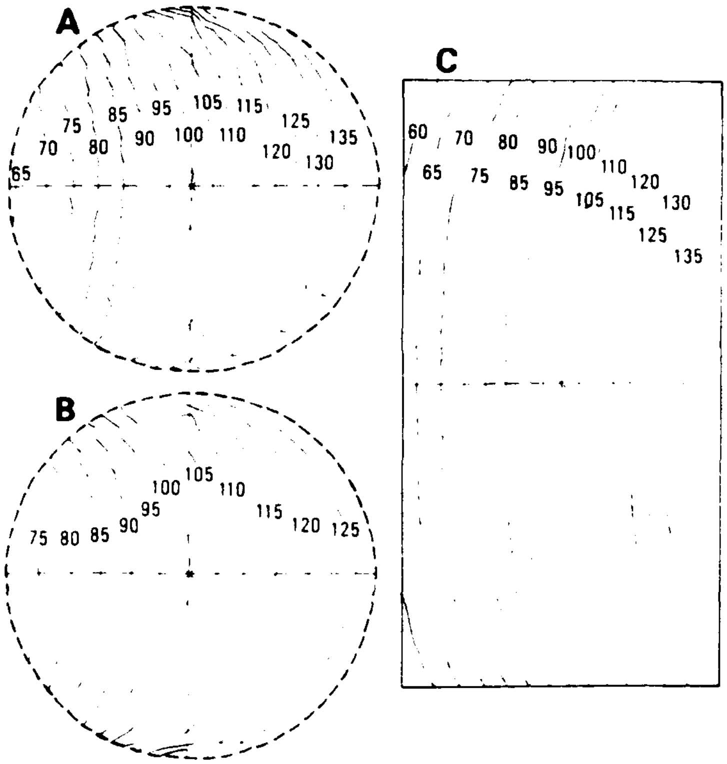

Figure 1. Calculated distributions of dose in a cylindrical phantom (15 cm diameter, 32 cm height) unilaterally irradiated at distances of (A) 100 cm, central transverse cross section, (B) 300 cm, central transverse cross section, and (C) 100 cm, central longitudinal cross section

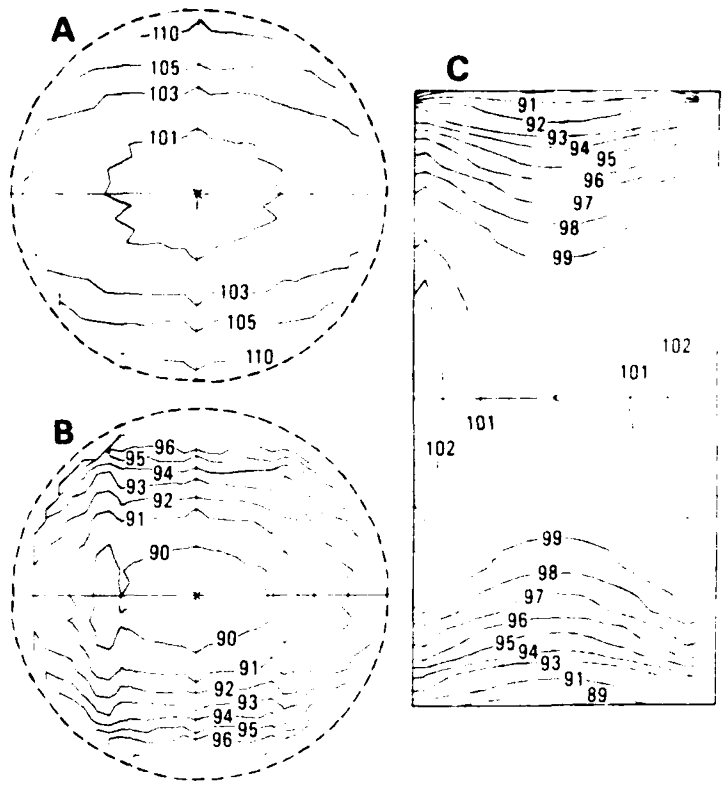

Figure 2. Calculated distributions of dose in cylindrical phantom (15 cm diameter, 32 cm height) bilaterally irradiated at 100-cm distance in (A) central transverse cross section, (B) transverse cross section 1 cm from end of phantom, and (C) central longitudinal cross section

Table 2. Tissue-to-Air Ratios*

Phantom	Exposure	Distance (cm) From Source	Calculated	Experimental
Large:	Unilateral	100	0.885	0.867
		200	0.885	0.877
		300	0.885	0.873
	Bilateral	100	0.885	0.868
		200	0.885	0.863
		300	0.885	0.863
Medium:	Unilateral	100	0.914	0.899
		200	0.914	0.898
		300	0.913	0.906
	Bilateral	100	0.914	0.898
		200	0.914	0.894
		300	0.913	0.890
Small:	Unilateral	100	0.950	0.945
		200	0.948	0.945
		300	0.948	0.936
	Bilateral	100	0.950	0.937
		200	0.948	0.929
		300	0.946	0.928
Short:	Unilateral	100	0.966	0.967
		200	0.966	0.970
		300	0.955	0.955
	Bilateral	100	0.966	0.966
		200	0.966	0.961
		300	0.955	0.955

*TAR's apply to midline of central cross section of each phantom.

Experimental and calculated patterns of depth dose for the central cross sections were compared at three critical points near the surface of the front (beam entrance), back (beam exit), and side (beam tangent) of each phantom (see Tables 3-5). For these comparisons, the calculated values were taken from contours of depth dose as shown in Figures 1 and 2. Agreement between calculated and measured dose distributions was within 2% for most points; the greatest difference was 4.4%.

Table 3. Large-Phantom Depth-Dose Patterns*

Distance (cm)	Exposure	Position	Calculated (%)	Experimental (%)
300:	Unilateral	Front	123	127
		Back	74	72
		Side	109	109
	Bilateral	Front Back	100	100
		Side	109	109
200:	Unilateral	Front	128	129
		Back	73	70
		Side	108	110
	Bilateral	Front Back	101	101
		Side	110	109
100:	Unilateral	Front	136	136
		Back	68	71
		Side	107	108
	Bilateral	Front Back	102	102
		Side	108	108

* Numerical entries in Tables 3-6 represent dose at each point, relative to a dose of 100% at midline in central cross section of each phantom

Table 4. Medium-Phantom Depth-Dose Patterns

Distance (cm)	Exposure	Position	Calculated (%)	Experimental (%)
300:	Unilateral	Front	118	121
		Back	79	77
		Side	107	106
	Bilateral	Front Back	99	99
		Side	106	106
200:	Unilateral	Front	119	123
		Back	77	77
		Side	107	106
	Bilateral	Front Back	100	100
		Side	106	106
100:	Unilateral	Front	127	127
		Back	[illegible]	74
		Side	106	104
	Bilateral	Front Back	100	101
		Side	107	107

Table 5. Small-Phantom Depth-Dose Patterns

Distance (cm)	Exposure	Position	Calculated (%)	Experimental (%)
300:	Unilateral	Front	113	114
		Back	84	84
		Side	106	105
	Bilateral	Front Back	99	99
		Side	105	105
200:	Unilateral	Front	114	115
		Back	84	82
		Side	104	104
	Bilateral	Front Back	99	100
		Side	103	104
100:	Unilateral	Front	118	119
		Back	80	81
		Side	103	103
	Bilateral	Front Back	99	100
		Side	103	103

Finally, measured and calculated patterns of depth dose were compared in cross sections 1 cm from the end of the phantoms (i.e., near the head or tail). At this location the measured doses were consistently higher than calculated, with a maximum difference of 14.4% (Table 6).

Table 6. Depth-Dose Patterns Near Phantom Ends

Phantom	Distance (cm)	Exposure	Position	Calculated (%)	Experimental (%)
Large:	300	Unilateral	Center	88	94
			Front	111	127
			Back	66	67
			Side	99	107
Large:	100	Bilateral	Center	90	93
			Front Back	92	98
			Side	96	103
Medium:	300	Unilateral	Center	89	95
			Front	104	119
			Back	70	73
			Side	97	104
Small:	300	Unilateral	Center	90	96
			Front	101	113
			Back	76	79
			Side	96	103

DISCUSSION

The results of this study demonstrate that an AECL radiotherapy treatment-planning computer (TPC) may be used successfully, with certain limitations, for calculating dosimetry for irradiations of the AFRRI Cobalt-60 Facility. Accurate TAR's were obtained when the TPC was operated in the irregular field mode, and patterns of central cross-section depth dose generated in the regular field mode agreed well with measurements made at selected points. Difficulties with the TPC arose in the inaccuracy of TAR's obtained from operation in fixed rectangular beam mode and also apparent errors in calculated dose patterns near the ends of each phantom.

The following factors contraindicate the use of standardized TPC programs for the AFRRI Cobalt-60 Facility: (a) The AFRRI Cobalt-60 Facility is a large, uncollimated source compared to the small, well-collimated sources used in typical teletherapy units. (b) The roughly 3% scatter component of the AFRRI Cobalt-60 Facility arises primarily from the floor of the room, whereas scatter radiation from a teletherapy unit is primarily forward scatter from the collimator. (c) The TPC is normally used for small-field irradiation of relatively large objects, whereas the AFRRI Cobalt-60 Facility is used for total-body irradiations of small objects. Consequently, it is not surprising that the calculated patterns of depth dose near the ends of the phantoms differed appreciably from measured values.

The inaccurate TAR's generated in operation of the fixed rectangular beam mode indicate that due caution is required when using any TPC. Comparison of TAR's for several different configurations led to the conclusion that the TPC used a simple reference table of TAR's based on depth and size of field when in the fixed rectangular beam mode. Only in the irregular field mode did the TPC use the dimensions of the phantom in calculating TAR's.

Finally, the data in this report illustrate the degree of nonuniformity in doses delivered to cylindrical phantoms irradiated in the AFRRI Cobalt-60 Facility. The data are summarized in the following:

In unilateral irradiations, the maximum dose was delivered to the center of the front surface of the cylinder and the minimum dose to the back, near either end.

Even for the small phantom, unilateral irradiations were neither uniform nor moderately uniform. [As defined by the International Commission on Radiation Units and Measurements (3), uniform and moderately uniform dose distributions are those in which the ratios of the maximum dose to the minimum dose are below 1.10 and 1.30, respectively.]

For bilateral irradiations, the maximum dose was delivered to the side surface (beam tangent) and the minimum dose to the midline, near either end.

For the larger phantom (15 cm in diameter), even bilateral irradiation did not produce a uniform dose distribution.

The above findings emphasize the importance of detailed studies of depth dose, particularly for specimens larger than about 12 cm in diameter irradiated in the AFRRI Cobalt-60 Facility.

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